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CARDIOLOGY DIVISION
Biomedical Technology Transfer

PREFACE

The Stanford University School of Medicine Biomedical Technology Transfer Team is directed by D.C. Harrison, M.D., and under the management of H.A. Miller, Deputy Director.

Other members of the Stanford professional staff who contributed to the preparation of this report are Mrs. D.L. Hall and Mr. A.G. Buck.

MONTHLY REPORT NO. 9

March, 1972

CONTRACT NO. NASW 2216

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SUMMARY OF ACTIVITIES

I. Narrative

Sixteen problems have been accepted by this program to date, of which four problems have been successfully transferred, one of these during March. A detailed report of this technology transfer is included in this monthly report on pages 12 a and b.

During the month of March, three new problems were accepted as follows:

> "Unsteady Flow Through Heart Valves," which concerns the flutter of valve leaflets and its effect on heart performance.
>
> "Radiotelemetry of Intracranial Pressure." This concerns long-term quantitative, continuous monitoring of critical intracranial pressure resulting from trauma.
>
> "ECG Monitoring During Emotional Stress." The purpose is to provide means for monitoring the ECG's of subjects undergoing commonly occurring professional and social stresses. Such stresses are often contributory to fatal arrhythmias.

Equipment and materials are being procured on two current problems. A feasibility study related to non-invasive intracranial pressure monitoring (PMD-1) has been undertaken with promising results.

Program discussion and presentation were performed before twelve distinct medical groups. Appointments for program presentations in the following months have been secured with three major medical institutions.

SUMMARY OF ACTIVITIES

II Tabular

Activity	Number This Month	Number Cumulative Since 7/71	On Page
Problems:			
New Problems Accepted	3	16	3
Active Problems	12	16	4
Searches by Computer:			
Searches Initiated	0	3	6
Searches Evaluated by Investigator	0	3	7
Problem Statements:			
Submitted to NASA for Review	0	0	8
Disseminated for Possible Solutions	0	0	9
Responses Received	0	0	10
Engineering Development in Progress	9	12	11
Technology Transferred	1	4	12

PROBLEMS

I. New Problems Accepted

Problem Number	Problem Title
CED-1	ECG Monitoring During Emotional Stress
VMC-1	Radiotelemetry of Intracranial Pressure
COH-1	Unsteady Flow Through Heart Valves

PROBLEM ACQUISITION AND REVIEW

Problem No: CED-1 Submission Date: 3/8/72

Problem Title: ECG Monitoring During Emotional Stress

Institution: Cedars of Lebanon Hospital, Los Angeles, California

Department: Cardiology

Investigator: James Forrester, M.D.

BTT Consultants: David Cannom, M.D.; A.G. Buck

Problem Objective: To measure the ECG reaction to emotional stress of professional, scientific and executive personnel.

Background: Serious arrhythmias and sudden death frequently occur during the everyday stress encountered by some occupational groups. How such stress affects the cardiovascular system is poorly understood.

There is a need for data on the cardiovascular effects of emotional stresses frequently experienced by members of certain occupational groups; e.g., surgeons, executives, scientists.

The determination of ECG stress relationships may provide a basis for training such individuals in what situations to avoid.

The work of the NASA on light-weight, non-encumbering telemetry equipment may provide the means of instrumenting subjects for research on this problem.

PROBLEM ACQUISITION AND REVIEW

Problem No: VMC-1 Submission Date: 3/8/72

Problem Title: Radiotelemetry of Intracranial Pressure

Institution: Valley Medical Center, San Jose, California

Department: Neurosurgery

Investigator: G. Silverberg, M.D.; R.D. Hamilton, M.D.

BTT Consultants: William H. Barry, M.D.; James A. White

Problem Objectives: To provide a non-encumbering system for measuring intracranial pressure over periods of five to ten days.

Background: The development of intracranial pressure following head injury may take several days. Present clinical techniques often indicate serious situations only after irreparable damage has occurred. Precise knowledge of increased pressure before such damage has been done should permit proper treatment in time to save the patient.

It is important that no encumbering wires or harness be employed. A small telemeter subcutaneously implanted and a pressure sensor, implanted above the dura, would fill the requirements.

It is believed that development of a suitable pressure sensing and telemetering system is feasible within the present state of the art with the support of NASA experience and expertise.

PROBLEM ACQUISITION AND REVIEW

Problem No: COH-1 Submission Date: 3/20/72

Problem Title: Unsteady Flow Through Heart Valves

Institution: City of Hope Medical Center, Duarte, California

Department: Cardiology

Investigator: Simon Rodbard, M. D.

BTT Consultants: William H. Barry, M.D.; Manley J. Hood

Problem Objectives: To provide methods for analysis of the dynamic flow through bicuspid valves and flutter of valve leaflets.

Background: At and above certain critical flow rates, the tips of the leaflets of bicuspid valves close and open many times per second, generating a murmur-like acoustic signal. With the increase of leaflet flutter, blood flow diminishes. Dr. Rodbard knows of no adequate computer simulation of this phenomonon.

A suitable computer simulation is desired to promote understanding of the phenomonon and possibly the interpretation of heart murmurs. Improved understanding might suggest means for alleviating some cardiac problems related to valvular dysfunction.

PROBLEMS

III Active Problems

Number	Status	Title
PAM-2	E	Temperature Telemeter for GI Tract Diagnosis
PMD-1	E	Non-invasive Intracranial Pressure Monitor
SSM-2	E	Electrode Applications to Myoelectrical Control
AMC-1	C	A Miniature Portable Patient Arrhythmia Detector
UCD-2	E	Digital Transmission of Medical Data
SSM-3	E	Nerve Conduction-Velocity Electrodes
CCH-1	E	Electrodes for Hemiplegia Research
VSF-1	E	Respiration and Phonation Electrodes
ELC-2	R	Tissue Transilluminating Surgical Light
CED-1	E	ECG Monitoring During Emotional Stress
COH-1	C	Unsteady Flow Through Heart Valves
VMC-1	C	Radiotelemetry of Intracranial Pressure

STATUS CODE:
R - Problem Acquisition and Review
S - Technology Search
C - Consultation
E - Engineering Development
A - Trial Applications
T - Technology Transferred
F - Final Reporting

PROBLEMS

III Completed or Inactive

The following problems have undergone successful technology identification and transfer. They are classified as inactive while the problem originator undertakes programmed research or clinical application. Periodic follow-up is planned.

Number	Status	Title
PAM-1	I	Miniature ECG Telemetry Unit for Ambulatory Patients
ELC-1	I	Apnea Monitor for Wide Range of Patients and Applications
UCD-1	I	Vectorcardiogram Computer Analysis for Exercised Subjects
SSM-1	I	Detection of Turbidity, Birefringence, and Fluoresence Changes in Cardiac Muscle

STATUS CODE: C - Completed
I - Inactive

SEARCHES BY COMPUTER

I Initiated

No searches initiated this month.

SEARCHES BY COMPUTER

II Evaluated By Investigator

None received this month.

PROBLEM STATEMENTS

I Submitted To NASA For Review

None submitted this month.

PROBLEM STATEMENTS

II Disseminated For Possible Solutions

No problem statements disseminated this month.

PROBLEM STATEMENTS

III Responses Received

No responses received this month.

ENGINEERING DEVELOPMENT

Application Technology and Source	Problem	Effort Started	Status
NASA-Ames, Instr. Div. Skylab Program Pope, Fryer, Westbrook	PAM-2	9/28/71	New radiosonde ordered by Stanford was delivered. A receiver was loaned to the problem originator by NASA-Ames. The problem originator is evaluating the equipment and technology.
NASA-Ames, RF & I Div. Rositano	SSM-2	10/21/71	Sample electrode configurations have been furnished to Mrs. Robertson for approval.
NASA-Ames, RF & I Div. Rositano	CCH-1	10/04/71	Special electrode material awaited from second manufacturer. First supply source failed to deliver as agreed.
NASA-Ames, RF & I Div. Rositano	VSF-1	11/04/71	Special electrode material awaited from second manufacturer. First supply source failed to deliver as agreed.
NASA-Ames, RF & I Div. Rositano	SSM-3	11/18/71	Special electrode material awaited from second manufacturer. First supply source failed to deliver as agreed.
NASA-Ames; Ogden, Billingham & Winter	PMD-1	1/13/72	Isotope test measurements have been made successfully. Instrumentation-funding request will be made to Navy.
NASA-MSC & GSFC Bloom	UCD-2	1/05/72	NASA-GSFC and NASA-MSC equipment has been gathered at MSC. Delivery to Dr. Walters awaits only legal loan-transfer papers.
NASA-Ames, RF & I Div. Donaldson & Beam	ELC-2	2/29/72	Investigation of special hardware is being made.
NASA-Ames, TUO; SwRI	CED-1	3/20/72	Equipment is being procured from SwRI.

TECHNOLOGY TRANSFERRED

Appropriate NASA technology has been identified and transferred to the following problems during this month. Detailed transfer reports are found on subsequent pages.

Problem Number	Title
SSM-1	Detection of Turbidity, Birefringence and Fluoresence Changes in Cardiac Muscle.

TECHNOLOGY APPLICATION

NASA TECHNOLOGY PROVIDES INFORMATION ON EXCITATION-CONTRACTION COUPLING IN MUSCLES

Problem No:	SSM-1	Acquisition Date:	Sept. 13, 1971

Problem Title: Detection of Turbidity, Birefringence and Fluorescence Changes in Cardiac Muscle

Institution: Stanford University School of Medicine

Department: Medicine, Cardiology

Investigator: William H. Barry, M.D.

BTT Consultants: William H. Barry, M.D.; A.G. Buck

Problem Objective: To develop an optical system for determining changes in turbidity and birefringence of muscle segments in vitro during isolated cardiac contraction.

Background & Description: Changes in optical properties of nerve tissue and skeletal muscle have been detected during excitation and contraction by using a battery-powered quartz-iodine light source. A ten-stage photomultiplier and a computer of average transients was used to detect reflected light. However, the tissues used in these studies were much larger than the cardiac muscle segments presently employed. A coherent light beam no larger than 0.5 mm in diameter is needed. The light intensity must not damage muscle tissue and the wave length should be preferably within the visible range. The detecting system must resolve changes of the order of 10^{-3} to 10^{-4} of the resting light intensity.

Resolution: The BTT consultants suggested that a laser light source with fiberoptics could provide the needed coherent light in a small working area. A conference was held with Dr. Leonard P. Zill, Chief of the NASA-Ames Exobiology Division and Mr. Benjamin H. Beam, Assistant Chief of the NASA-Ames Research Facilities, and a laser chopper system, such as was used previously by Mr. Beam in a hydrocarbon detector, was adopted. The necessary equipment has been loaned by Ames to the problem originator for use in his research.

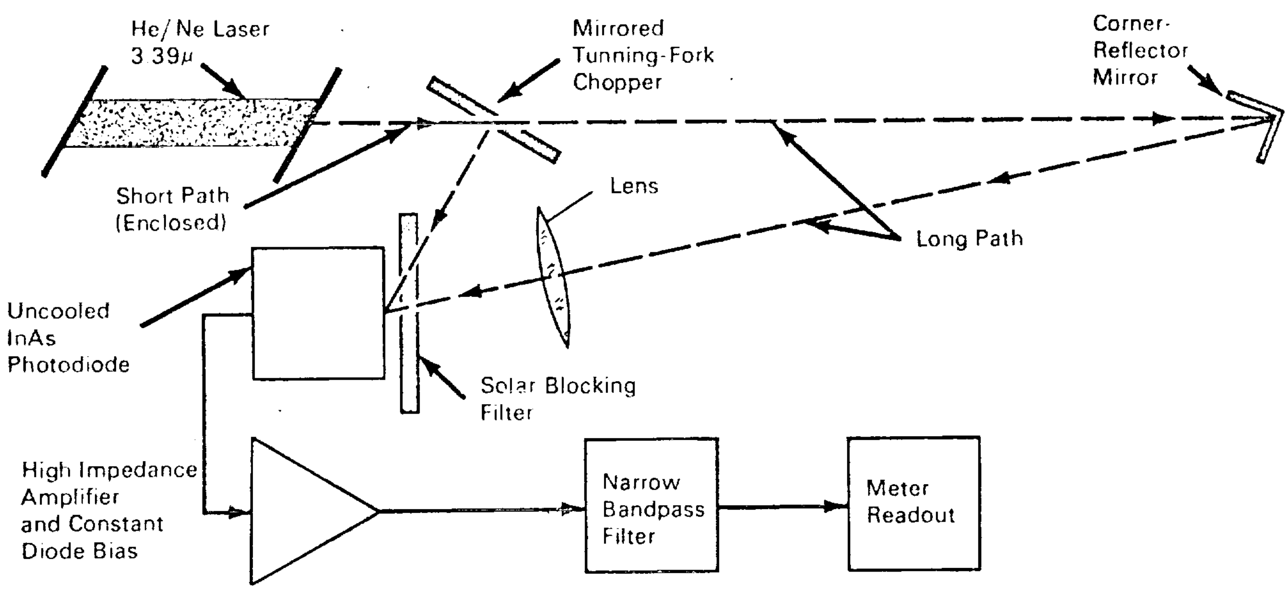
Technology Identification: The basic technology responsible for resolution of this problem is found in NASA Tech Brief No. 70-10631 and in ARC-10156. The helium-neon gas laser is of commercial manufacturer; the chopper is of NASA-Ames design and manufacture.

Impact: Optical studies of cardiac muscle will provide new information about excitation-contraction coupling. This information is likely to increase understanding of the contraction process in muscle. It will aid in the definition of the mechanism of action of numerous drugs which affect the strength of contraction of the heart and which are used to treat heart failure.

Documentation: NASA Tech Brief 70-10631; Ames Report ARC-10156, "Laser Beam Hydrocarbon Detector."

NASA TECH BRIEF

Laser Beam Hydrocarbon Detector



The problem:

To detect low-level concentrations of hydrocarbon vapors which may constitute a toxic, combustible, or explosive hazard.

The solution:

A portable instrument which passes light from a helium-neon laser at a wavelength of 3.39 microns through the atmosphere being monitored and measures the attenuation of the laser beam. The attenuation of the original beam is due almost exclusively to absorption of radiation by hydrocarbons; therefore a quantitative measure of their concentration is available.

How it's done:

As shown in the figure, a helium-neon laser beam at 3.39 microns is intercepted by a mirrored tuning fork chopper which alternately reflects the light directly to the detector or allows it to traverse a longer path to a corner reflector which returns it to the detector. The longer path is about two meters overall, while the short path (enclosed in a protective box) is only a few centimeters. The detector is an uncooled indium-arsenide photodiode which is reasonably efficient at 3.39 microns. A solar blocking filter prevents spurious signals from sunlight when the instrument is used outdoors.

The instrument is adjusted so that the light intensity received via the long path is exactly equivalent to that from the short path when no hydrocarbons are present. The presence of an absorbing gas in the long path results in a difference of signal strength from the long and the short path; the ac component of this

(continued overleaf)

signal is subsequently filtered, amplified, and indicated on a meter.

The design of the detector circuit is straightforward; the indium-arsenide photodiode is held at near-zero voltage bias by the operational amplifier since operation in this mode produces less dark current, distortion, and bias shift. The amplifier output voltage is proportional to the product of photodiode current and feedback resistance, and is linear with incident irradiance for several decades. This signal is fed to a bandpass filter in order to increase the S/N ratio and to enhance nulling capability.

Since the stability of the system is critically dependent on the stability of the light beam chopper, it is operated at constant amplitude and further stabilized by a feedback loop in which the mechanical structure of the chopper is incorporated in the tuned circuit of the feedback oscillator. In this arrangement, voltage induced in a sensing coil by the motion of the chopper is proportional to the velocity of the chopper blade; this voltage is amplified and applied to a bridge containing two back-to-back zener diodes; the unbalanced signal from the bridge is amplified and supplied to the chopper drive coil. At low amplitude, the zener diodes have a high resistance and act as linear circuit elements; hence, when the chopper drive is first turned on, positive feedback is applied to the drive coil and the chopper begins to oscillate. At high amplitudes, the impedance of the zener diodes drops, reducing the unbalanced signal until it is just sufficient to keep the amplitude from rising further. This simple circuit is quite effective in producing stable operation in a variety of adverse environments.

The prototype instrument was arranged to be handcarried and was tested in the field, operating from a lead-acid battery and converter carried in an automobile. The sensitivity was limited by mechanical instabilities in maintaining optical alignment in field conditions, but was sufficient for detecting natural gas at concentrations of about one part per million. This concentration is well below the health hazard level and considerably below explosive concentration.

Reference:

Jaynes, D. N.; and Beam, B. H.: Hydrocarbon Gas Absorption by a HeNe Laser Beam at a 3.39-Micron Wavelength, Applied Optics, vol. 8, August 1969, page 174

Notes:

1. Disadvantages of the prototype instrument are: (1) the potential hazard of the high-voltage supply in an explosive environment; (2) the presence of dust in the long path gives spurious indications of hydrocarbons; (3) hydrocarbons cannot be identified.
2. Requests for further information may be directed to:

   Technology Utilization Officer
   Ames Research Center
   Mail Stop N-240-2
   Moffett Field, California 94035
   Reference: TSP70-10631

Patent status:

No patent action is contemplated by NASA.

Source: B. H. Beam, D. N. Jaynes, and C. N. Burrous
Ames Research Center
(ARC-10156)

ADDITIONAL TECHNICAL INFORMATION

The following pages include:

(1) A reprint of Hydrocarbon Gas Absorption by a HeNe Laser Beam at a 3.39-Micron Wavelength," by D.N. Jaynes and B.H. Beam, in Applied Optics, Vol. 8, page 1471, August 1969.

(2) A reproduction of the presentation "Hydrocarbon Gas Detection Using a HeNe Laser," made by B.H. Beam, D.N. Jaynes, and C.N. Burrous, at the May 1969 meeting of the Instrument Society of America, Las Vegas, Nevada.

ARC-10156

Reprinted from APPLIED OPTICS, Vol. 8, page 1741, August 1969

Hydrocarbon Gas Absorption by a HeNe Laser Beam at a 3.39-μ Wavelength

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Received 2 October 1968.

The helium-neon laser emission line at 3.39 μ is of great interest for spectroscopy because it is near the fundamental vibration frequency of the coupling between the hydrogen and carbon atoms. The force constant for the C–H stretching bond varies from k = 480–600 N/m.[1] The specific value depends on the influence of adjacent atoms, and particularly on the bonding to the three other valence vacancies in the carbon atom. This force constant and the reduced mass of the hydrogen atom (always fairly close to $\mu = 1.6 \times 10^{-27}$ kg) yield a radiation wavelength corresponding to the fundamental vibration of

$$\lambda = 2\pi c(\mu/k)^{\frac{1}{2}} \sim 3.1\text{-}3.4\ \mu,$$

where $c = 3 \times 10^8$ m/sec. Photons will be absorbed in hydrocarbons near this vibration frequency and at specific frequencies determined by quantized vibration-rotation levels. For methane, the difference between discrete absorption frequencies is determined by the formula,

$$\Delta\lambda = 2B\lambda^2 \text{ with } B = 5.25 \text{ cm}^{-1}.$$

This gives the wavelength difference between absorption lines, $\Delta\lambda$, as 0.012 μ (10.5 cm^{-1}) for methane. Other hydrocarbon molecules, not having the spherical symmetry of methane require a more complicated formula, but in general the heavier hydrocarbons will have smaller spacing between absorption lines. The line half-widths of the absorbing gas depend on gas temperature and pressure, but even at low pressures and at room temperature, line half-widths are about 10^{-5} μ (0.01 cm^{-1}).[3] The structure of the He–Ne laser emission at 3.39 μ for a laser cavity length of 0.3 m is that of a single, very narrow emission line under a doppler-broadened envelope. A laser having a cavity length of 0.3 m emits lines having a half-width of 10^{-9} μ (10^{-6} cm^{-1}) or less[4] and separated by about 10^{-5} μ (0.01 cm^{-1}). This line separation is about the same as the doppler width of the emission envelope, so that the laser operates in essentially a single mode. From these considerations, it is clear that absorption of a He-Ne laser beam at 3.39 μ by hydrocarbon gases will not necessarily be related to spectroscopic absorption coefficients obtained at low resolution, and will depend primarily on the location of the laser emission line on the vibration-rotation absorption line of the hydrocarbon.

We have measured the absorption coefficients of a number of hydrocarbon gases for a laser beam at 3.39 μ. The experimental equipment consisted of a 1-mW He–Ne laser, a 400 cps chopper, an absorption cell with sapphire windows, an uncooled indium arsenide detector, and a lock-in amplifier. The absorption cell was evacuated with a roughing pump. Sets of measurement were taken with the cell evacuated and filled with hydrocarbon gas over a range of pressures at room temperature. Other sets of measurements were taken with an air and hydrocarbon gas mixture in the cell at standard room temperature and pressure. According to the Lambert-Beer law, the transmittance through the gas sample is

$$T = e^{-\alpha p x},$$

where x is the length of the sample chamber measured in centimeters and p is the gas pressure in atmospheres; the absorption coefficient α is (cm-atm)$^{-1}$. The transmission data were plotted on semi-log paper as a function of gas pressure, and α calculated from the slope of the line obtained. For all gases, a straight line was obtained over the entire range of pressures shown in the table.

Table I. Room-Temperature Absorption Coefficients of Hydrocarbon Gases at a Wavelength of 3.3913 μ

Alkane series	Pressure range 0.001 atm to	α (cm-atm)$^{-1}$
Methane	0.04 atm	48–52
Ethane	0.01	2.7
Propane	0.03	8.3
Pentane	0.015	13.6
Hexane	0.015	18
Heptane	0.01	20
Decane	0.004	10–13[a]
Ether	0.05	5.5
Ethyl alcohol	0.07	2.8
Gasoline	0.02	10.5
Toluene	0.01	5.7
Acetone	0.15	1.1
Kerosene	0.003	7–13[a]
Jet fuel (JP-4)	0.03	17
Jet fuel (JP-5)	0.003	20–24[a]
Hydrocarbon gas in air	**Partial pressure of H-C gas**	**α (cm-atm)$^{-1}$**
Methane	0.05	15
Ethane	0.13	8.9
Propane	0.05	20

[a] Uncertainty due to low vapor pressure at room temperature.

As the pressure of the hydrocarbon gas is increased, the line is broadened and shifted toward longer wavelength.[5] When the gas is pressure-broadened, the transmission of the laser light will be different from that for the pure gas and will depend on the pressure-broadening coefficient, the location of the laser line with respect to the absorption line of the gas, and on the amount the absorption line is shifted due to gas pressure.

The results are tabulated in Table I. As expected, the data show rather wide variations in absorption coefficient from spectroscopic data. For example, spectroscopic data at low resolution[6] show that ethane absorbs more strongly than methane, while the reverse is shown by our data.

Our interest was related to the detection of low concentrations of hydrocarbon gases in air at room temperature. We have applied these data in the design of instruments for detection of combustible gases. Although any particular hydrocarbon cannot be identified from one measurement such as this, there are other applications such as hydrocarbon level in fuel storage areas, methane concentration in mines, or introduced into gas flows for diagnostics in wind tunnels, where a general indication of hydrocarbon content is desired.

References

1. G. Herzberg, *Infrared and Raman Spectra* (D. Van Nostrand, Inc., Princeton, N.J., 1945), p. 193.
2. D. E. Grey, Ed., *American Institute of Physics Handbook* (McGraw-Hill Book Co., New York, 1963), pp. 7–163.
3. A. Mitchell and M. Zemansky, *Resonance Radiation and Excited Atoms* (Cambridge University Press, New York, 1961), pp. 99–102.
4. A. Javan, E. A. Ballik, and W. L. Bond, J. Opt. Soc. Amer. **52**, 96 (1962).
5. H. Goldring, A. Szoke, E. Zamir, and A. Ben-Reuven, J. Chem. Phys., **15**, 4253 (1968).
6. R. H. Pierson, A. N. Fletcher, and E. S. C. Gantz, Anal. Chem. **28**, 1218 (1956).

HYDROCARBON GAS DETECTION USING A HeNe LASER

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ABSTRACT

A prototype instrument for detecting hydrocarbon vapors using a laser is described. The instrument utilizes the absorption by a hydrocarbon gas of the 3.39 μ HeNe laser radiation. The spectroscopic details of the measurement are discussed along with the detector electronics and other practical problems. Experimental data obtained with the prototype instrument are presented.

INTRODUCTION

Because of its interest in aerodynamic research, Ames Research Center is concerned with the development of better gas diagnostic tools for use with its wind tunnels and in the detection of hazardous or explosive concentrations of combustible vapors in aircraft and ground facilities. It is also apparent that because of the importance of hydrocarbons in the human environment, any equipment developed to detect small concentrations of hydrocarbon fuels may find many peripheral uses.

DISCUSSION OF SPECTROSCOPIC DETAILS

It is fortuitous that the helium-neon laser develops a significant light intensity at a wavelength of 3.39 μ, and that this coincides approximately with a fundamental absorption band for all hydrocarbons. This is illustrated by the representative spectra of hydrocarbon gases in figure 1.[1] The strong absorption shown in the vicinity of 3.39 μ results primarily from the stretching vibration between the hydrogen and the carbon atoms. This absorption is present in every hydrocarbon molecule, the precise frequency and width of the absorption line depending upon details of molecular structure and the molecular environment. It is also fortunate that most common gases and vapors which do not contain hydrocarbons do not absorb in this region. For example, water vapor, CO_2, and ammonia vapor are quite transparent at 3.39 μ. The absorption spectrum of methane which appears as a band on figure 1 is shown in much finer detail in figure 2. The upper curve shows the $\nu 2$ fundamental of methane in high resolution.[2] The fundamental stretching vibration transition frequency corresponds to the point Q on the figure, and the family of fine absorption lines represents quantized rotation levels around this vibration frequency. The 3.39 μ laser line corresponds approximately to the 7th line in the P branch in figure 2.

This P-7 absorption line can be considered in still finer detail to illustrate the relations involved when methane is exposed to the laser beam, both as a pure gas at low pressure and when mixed with another gas that does not absorb at 3.39 μ. Some of these relations are illustrated in figure 3. The calculated Doppler width of the methane absorption line at low pressures is 8.9×10^{-3} cm^{-1}. This agrees approximately with experimental measurements[3] taken at 0.5 torr. At low pressure, the methane absorption line center is at 2947.906 cm^{-1} and shifts uniformly with pressure to longer wavelengths with the addition of a foreign gas.[4] If the frequency shift for methane in air can be inferred from the data of reference 3 as the average between the observed shifts in neon and argon, the resulting shift amounts to about 7×10^{-3} cm^{-1} at atmospheric pressure in air. This shift is therefore presumed to be a less important effect than line broadening for mixtures of methane and air. The line broadening effect of gas pressure would be expected to become very important at pressures above about 50 to 100 torr. At atmospheric pressures, the pressure broadened absorption line is calculated to be about $93\cdot10^{-3}$ cm^{-1} wide,[3] and is shown on an absorption scale to compare with that for the pure gas in figure 3. The broadening of the line reduces the absorption markedly at the line center but increases the absorption in the wings.

The characteristics of the HeNe laser are also shown in figure 3. The center of the Doppler envelope of the laser emission[3] is at 2947.903 cm^{-1}, and the Doppler line width[5] is about 9.3×10^{-3} cm^{-1} wide assuming an effective temperature of 400°K.[5,6] For a laser cavity 30 cm long, the laser modes at 3.39 μ are separated by 15×10^{-3} cm^{-1}. The cavity modes are thus separated by a distance greater than the half-width of the Doppler envelope, and the laser oscillates in what is essentially a single mode. It is worth noting in passing that this is a much simpler situation than when the same laser (same cavity length) is oscillating at 0.63 μ, the laser modes are separated by 0.6×10^{-3} cm^{-1}, and about 20 separate oscillation modes can exist under the Doppler envelope.

The output of the laser at 3.39 μ is thus represented by the narrow emission line in figure 3.

It lies somewhere within the Doppler envelope shown, the precise oscillation frequency depending on the requirement for an integral number of wavelengths within the laser cavity. This precise frequency may vary with variations in cavity length due to temperature changes unless the laser is mode stabilized. Variations in this frequency will change the absorption of laser light in pure methane at low pressure, but the absorption of a mixture of methane in air will be virtually unaffected by mode stability because of the extreme width of the pressure-broadened absorption line compared with the Doppler width of the laser line.

Much less is known about the detailed structure of hydrocarbons having higher molecular weights or more complicated structure. We have measured the absorption coefficients of a number of hydrocarbon gases at a laser wavelength of 3.3913 μ. The method consisted in passing the laser beam through a 400 cycle chopper, then through an absorption cell containing the test gas, and into a detector. The transmitted signal was measured over a range of pressures at room temperature, and the data are presented in figure 4. The straight line variation for each gas represents a confirmation of the Lambert-Beer relation that optical depth is inversely proportional to the logarithm of the transmission. The data are presented as a ratio of the transmission through the gas (T) to the empty-cell transmission (T_0) as a function of the product of density and path length. The density referred to is the partial density of the selected hydrocarbon gas in the case of mixtures of the gas with air. The slope of the lines of figure 4 is thus the absorption coefficient. It is also apparent that the absorption varies widely between different gases and with pressure broadening for the same gas. Some deviations from the straight line representing a logarithmic relation were noted at higher pressures. The data of figure 4 have been summarized in a forthcoming letter to Applied Optics,[7] but the principal results are shown in figure 5. It is seen that the absorption coefficient varies considerably for the different gases, but is reasonably strong for all gases tested. For example, an absorption coefficient of 10 cm^{-1} $atmospheres^{-1}$ indicates that a 1.0 cm path in the gas will absorb about two-thirds of the incident beam if the pressure is one-tenth of an atmosphere. These data suggest a number of possible applications involving detection and diagnostic instruments.

DISCUSSION OF PROTOTYPE DETECTOR

We have recently built a hydrocarbon gas detector based on path length variations as shown in figure 6. In this device, a HeNe laser beam at 3.39 μ is incident on a mirrored tuning fork chopper which alternately reflects the light directly to the detector or allows it to traverse the longer path to the corner reflector and back to the detector. The long path shown was about two meters over-all, while the short path (enclosed in a protective box) was only a few centimeters. The detector was an uncooled indium-arsenide photodiode which is reasonably efficient at 3.39 μ. A solar blocking filter was used to eliminate spurious signals due to sunlight in an outdoor environment. The instrument was adjusted so that the light received via the long path was exactly equivalent to that from the short path. The introduction of an absorbing gas in the long path thus caused a deviation from null and produced a signal proportional to the quantity of absorbing gas. Figure 7 shows the variation of transmission of the long path as a function of time with and without an absorbing gas. With an absorbing gas, the difference in signal received via the long and the short path contained an AC component which was subsequently filtered, amplified, and indicated on the meter.

The electronic design for the detector circuit is straightforward. The detector amplifier and filter portion is shown in figure 8. The indium arsenide photodiode is held at near zero voltage bias by the operational amplifier. Operation in this mode produces less dark current, distortion, and bias shift. The amplifier output voltage is proportional to the product of photodiode current and feedback resistance, and is linear with incident irradiance for several decades. This signal is fed to a band-pass filter in order to increase the S/N ratio and enhance the nulling capability.

Since the stability of the system is critically dependent on the stability of light beam chopper, it was operated at constant amplitude, and stabilized by feedback. The design of the system that accomplishes this control is shown in figure 9. The system is a feedback oscillator in which the chopper mechanical structure forms the tuned circuit. The voltage from the sensing coil is proportional to the velocity of the chopper blade. This voltage is amplified and applied to a bridge containing two back-to-back zener diodes. The unbalanced signal from this bridge is amplified and supplies a drive coil. At low amplitude, the zener diodes have a high resistance and act as linear circuit elements. For this condition, positive feedback is applied to the drive coil and the chopper begins to oscillate. At high amplitudes, the impedance of the zener diodes drops, reducing the unbalanced signal until it is just sufficient to keep the amplitude from rising further. This simple circuit is quite effective in producing stable operation in a variety of adverse environments.

Figure 10 is a photograph of the crude prototype instrument. The system was arranged to be hand-carried and was tested in the field, operating from a lead-acid battery and converter carried in an automobile. Although its sensitivity was limited by mechanical instabilities, it was still sufficient for detecting natural gas at concentrations of about 1 part per million. This concentration is well below that which is hazardous to health and considerably below explosive concentration.

CONCLUSIONS

Since the initial tests with this prototype, our work has continued in several directions. It is apparent that the instrument is much larger than necessary to detect the small concentrations (1%) of natural gas and similar hydrocarbons in fires and explosions. Such small amounts are readily detectable with path lengths of the order of centimeters or even millimeters. There was more than adequate detection capability in the 1 mw laser and indium arsenide detector combination, so that the 30 cm laser tube could be miniaturized if desired. AC signal current in the detector at our limit of detection of 1 part per million was about 10^{-9} amp, and more sophisticated electronic circuitry would permit detection of currents several orders of magnitude smaller. This capability could be used to allow detection of smaller concentrations of gas or reduction of the laser size.

However, several difficulties also became apparent. The high voltage necessary to excite the laser is a potential hazard in an explosive environment, and special attention to insulation would be necessary to prevent sparking if the laser itself is immersed in the hydrocarbon gas. The presence of dust or material which would condense on or degrade the mirrors requires special attention in practical applications. It may be possible to excite the laser at two frequencies, however, and use the same instrument to measure dust by light scattering at the same time as the gas content is being measured.

Our immediate interest in applying the technique, however, is in gas diagnostics in wind tunnels, ducts, and other gas flow facilities. The small concentrations of hydrocarbon gas which can be detected in air streams suggest a method for seeding a gas and studying variations in gas density due to mixing, compressibility, and other phenomena of interest in aerodynamics.

KEY WORDS

Hydrocarbon detector, gas detector, explosion detector, combustible gas detector

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OTHER ACTIVITIES

Personal visitations by members of the Stanford University Biomedical Technology Transfer team were performed to present the details of the biomedical applications program to the following institutions:

March 1	University of California at San Diego Department of Anesthesia, N.T. Smith, M.D. and 15 associates were in attendance; Messrs. Buck and Miller (Stanford BTT representatives).
March 3	Valley Medical Center, San Jose, California Department of Neurosurgery, Drs. Hamilton and Silverberg; Messrs. White and Miller (Stanford BTT representatives).
March 8	Cedars of Lebanon Hospital, Los Angeles, California Department of Cardiology, Dr. William Parmley and 17 associates attended; Drs. E. Alderman, A. Rider and Mr. A.G. Buck (Stanford BTT representatives).
March 15	City of Hope Medical Center, Duarte, California Department of Cardiology, Dr. S. Rodbard Rancho Los Amigos Hospital, Los Angeles, California Drs. C. Stiles, D. McNeal and 3 staff attended. Good Samaritan Hospital, Los Angeles, California Departments of Thoracic and Cardiovascular Surgery Dr. Q. Stiles and 15 staff; Dr. W. Barry and Mr. A.G. Buck (Stanford BTT representatives for all three visits).
March 16	University of Nevada, School of Medicine, Reno, Nevada Department of Basic Medical Sciences, Dr. G. Smith, Dean and department heads and 20 associates attended; Drs. D. Cannom, R. Crow and Messrs. S. Davidsen and Harry Miller (Stanford BTT representatives).
March 23	Stanford University Children's Convalescent Hospital Dr. H. Jennisen and 15 staff members attended; Dr. W. Barry and Mr. M. Hood (Stanford BTT representatives).

March 29 San Francisco County General Hospital, San Francisco
Cardiopulmonary Department, Dr. T. Evans and 4 associates attended; Dr. A. Rider and Mr. S. Davidsen (Stanford BTT representatives).

* * *

The following individuals and institutions were contacted in Houston, Texas by Mr. Paul Purser (Stanford BTT) to discuss the Stanford University Biomedical Technology Transfer program and current medical problems for potential submission into the NASA TU program.

Herbert C. Alan,Jr., M.D.

Walter S. Henly, M.D.

Peron O. Jones, M.D.

Daniel E. Jenkins, M.D., Baylor University

Henry D. McIntosh, M.D., Chairman, Department of Medicine Baylor College of Medicine

James R. Hickox, Harris County Medical Society

Sidney Schnur, M.D., President, Harris County Medical Society and Texas Heart Association

Dudley Hafner, Executive Director, Texas Heart Association

Richard T. Eastwood, Ph.D., Executive Director, Texas Medical Center

Walter M. Kirkendall, M.D., Chief of Medicine, University of Texas Medical School

Donald N. Macon, Regional Medical Program of Texas

William A. Spencer, M.D., Director, Texas Institute for Rehabilitation and Research

* * *

On March 7, Mr. Sal Rositano (NASA-Ames) and Mr. H. Miller (Stanford BTT) were invited speakers at the Institute of Electrical and Electronic Engineers, San Francisco Group Chapter in Engineering in Medicine and Biology. A formal presentation of available NASA biomedical technology and the NASA technology utilization program was offered and concluded with a demonstration of working biomedical equipment. This meeting was attended by thirty representatives from industrial engineering groups, clinical and research medical specialities.

On March 13, Messrs. Davidsen and Miller (Stanford BTT) assisted in the arrangement and demonstration of the Langley Complex Coordinator in cooperation with the Stanford Research Institute's Technology Applications Team. This demonstration was held at the Stanford University School of Physical Medicine and attended by approximately 20 staff members.

* * *

On March 20, Messrs. Miller and Davidsen conferred with Dr. Richard Haines, Messrs. B. Evans and H. Emerson (NASA-Ames) regarding the clinical acceptance, status and commercial manufacturing plans for the Ames "Automatic Visualization Sensitivity Tester". Stanford consultants sought recommendations from several ophthalmology specialists and critiqued the production proposal received from a commercial firm.

* * *

Mr. A. G. Buck (Stanford BTT) attended a demonstration by Mr. J. Dimeff (NASA-Ames) and Dr. P. Portner (Arkon Company, Berkeley, California) of a carbon monoxide analyzer designed by NASA-Ames and produced by the Arkon Company. This demonstration was held on March 22 at the Cardiovascular Research Institute of the University of California School of Medicine in San Francisco and attended by Drs. J. Nadel and Garreth Jones. At the same institution, Drs. Malcolm McIlroy and Hans Astrom were consulted about the potential uses of the NASA-Ames Exoskeletal (hardsuit) technology as applied to medical plethysmographic studies. These two areas will be followed up in close detail.

* * *

On March 27, Dr. Donald C. Harrison participated in the Fourth National Conference on Electronics in Medicine held in Chicago, Illinois. Other panel members were Mr. J. T. Richards, Jr., Drs. D. Culclasure and F. T. Wooten and Mr. R. Zimmerman. The purpose of the program was to permit the physician, engineer and health-science administrator to share their experiences in transferring aerospace technology to medicine.

On March 30, a meeting was held at the Stanford BTT offices and attended by Dr. David Winter (Deputy Director, Life Sciences, NASA-Ames), Dr. Harold Sandler (Chief, Biomedical Research Division, NASA-Ames), Dr. Donald C. Harrison and Mr. H. Miller (Stanford BTT). The purpose of this meeting was to discuss various types of new technology from NASA-Ames available for transfer into the biomedical community and to determine cooperative methods of utilizing time of Ames personnel requested to work on Technology Utilization problems. Preliminary arrangements are to be followed up by subsequent meetings to arrive at a cooperative and agreeable method of interaction.

PLANNED ACTIVITIES

Several cooperative animal research studies are to be undertaken involving the problem originator, Stanford BTT consultants, and other medical consultants associated with problem PMD-1. These research studies will expand on the methods and accuracy of using selected isotopic scanning methods to monitor intracranial pressure changes noninvasively.

* * *

Meetings are planned to present the details of the NASA Biomedical Technology Transfer program with the following groups:

Alviso Family Health Center, Alviso, California

Kaiser-Permanente Medical Group, Oakland, California

Good Samaritan Hospital, Eugene, Oregon

* * *

Computer searches of NASA technology are planned relevant to problems:

ELC-2 Tissue Transilluminating Surgical Lights

CED-1 ECG Monitoring During Emotional Stress

Appendix C

HOURS/EFFORT SUMMARY FOR THE PERIOD

PROBLEM RELATED	123
NON-PROBLEM RELATED ACTIVITIES	390
TOTAL HOURS FOR THE PERIOD	513

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